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# An Evaluation of Output Performance for Rainfall Evolution in Cordex-Africa Regional Models: The Case of the Medjerda Basin-Northern Africa

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## Abstract

*This work aims to evaluate the performance of outputs in six regional climate models (RCMs) of the Cordex-Africa program (RCA4, CRCM5, RACMO22T, HIRHAM5, REMO2009, CCLM4-8-17), at the Medjerda Watershed. It is based on the evolution of precipitation during the reference period (1981-2005) using different evaluation criteria (Pearson's correlation coefficient* ($r$)*, the root mean square error* ($RMSE$)*, the percentage of bias* ($PBIAS$)*, the Taylor Diagram and Taylor's Skill Score* ($TSS$)*). The results confirm the difference between the RCMs in the estimation of climatic variables at different time scales (annual, seasonal and monthly). The annual precipitation regime has been accurately predicted by REMO2009, which presents a result of 0% in terms of* $PBIAS$ *between observations and simulations. The agreement between the observed and simulated precipitations at a seasonal time scale is superior in terms of the correlation* $r = 1$ *by REMO2009, RACMO22T, CCLM4-8-17, CRCM5, HIRHAM5. In terms of* $RMSE$ *the REMO2009 model scored a low value of 1.13 mm in autumn, on a monthly time scale, while the CCLM4- 8-17 model showed a high performance value in terms of Taylor's Skill Score* ($TSS = 0.91$)*. In overall terms, those models, which reproduce the observed climatology of the Medjerda basin more efficiently, and which may be considered the most efficient, include REMO2009, CCLM4-8-17, RACMO22T and CRCM5. This study recommends the use of these selected models for future precipitation projections in the Medjerda Watershed and it is therefore necessary to correct the outputs of the regional models of the Cordex-Africa project and to use the set of those models that perform most efficiently with respect to future climate change impacts and for adaptation studies on the African continent.*

**Key words:** Cordex-Africa, climate change, Medjerda, performance, precipitations

## 1 Introduction

Concern regarding climate change has increased in recent years. As a result, the scientific community has become progressively more interested in assessing the environmental and socio-economic impact of these changes. This study aims to implement adaptation and mitigation measures for the sustainable management of water resources, agriculture, energy and biodiversity. However, the assessment of climate change and the planning of adaptation and mitigation strategies continue to be based on a chain of digital dynamical climate models that have become an effective tool in terms of assimilating climate change and in forecasting climate at different time scales (Umuhoza et al., 2021).

These tools are divided into two categories: global climate models (GCMs) and regional climate models (RCMs). GCMs allow for the simulation of the climate of the entire planet. However the direct use of GCM outputs remains relatively limited due to uncertainties that include: the parameterization of the climate models, the distance of the station from the nearest grid point, the resolution of the model used, and the distance from the sea, all of which considerably reduce the reliability of the results (Mendez et al., 2020; Mesta and Kentel, 2022). Many researchers have proven that the coarse spatial resolutions of GCMs have limitations in the simulation of hydrological variables at a regional scale (Stefanidis et al., 2020; Demissie and Sime, 2021). This leads to a dynamic scaling reduction presented by the regional climate models (RCMs) (Dixit et al., 2021), due to the fact that they produce finer-scale simulations that are capable of solving smaller-scale details, and the predicted errors may be less significant.

Several institutions are therefore aiming to produce large sets of RCM simulations that will be used for various applications in climate studies at regional spatial scales (Edenhofer, 2015). In this context, as mentioned by IPCC (2007), the climate models present difficulties when simulating key elements of the current climate, especially with respect to the African continent. As such it was necessary to extend the conception of the multiple interactions between the components of African climate in order to improve climate simulations and projections for this region. The World Climate Research Program (WCRP) (Ayugi et al., 2020) backed the launch of the CORDEX-Africa (Coordinated Regional Climate Downscaling Experiment) project. This initiative seeks to reduce the scale of different GCM outputs and to generate a set of both historical and future climate projections at a high resolution ($\sim$ 50 km) (Worku et al., 2018).

For the evaluation we used research by Ashaley et al. (2020), which examined four RCMs in the Africa-Cordex, in order to select the most efficient model contrasted to a set of mesh observation data on the Kpong irrigation system area (Ghana), with data from 1964 to 2005. This research used diverse performance criteria, such as the correlation coefficient ($r$), the $RMSE$, the standardized deviations ($\sigma$) and the Mann-Kendall trend analysis so as to determine the performance of the model. In general, the RCA4-CanESM2 model reproduces the climatology of precipitations and temperatures with a reasonable level of competence, and it has been suggested as being the most effective for climate impact assessment research in the study area. The work of Taïbi et al. (2021a) evaluated the performance of the RCA4-CNRM and RCA4-MPI-ESM-LR models of the Cordex-Africa project at the Ain Dalia basin, which is located in Oued Medjerda. The results concluded that these two models are efficient, and they were selected due to the lowest value of the estimated bias between the observed and simulated data during the reference period (1981-2010). Several other studies also focused on the use of regional models of the Cordex-Africa project (Taïbi et al., 2021b).

Regional climate models (RCMs) however simulate climate variables with different levels of precision, and significant biases may be found with respect to the region and the season. Therefore, in order to select the appropriate RCMs for a specific basin, the performance of several RCMs needs to be evaluated.

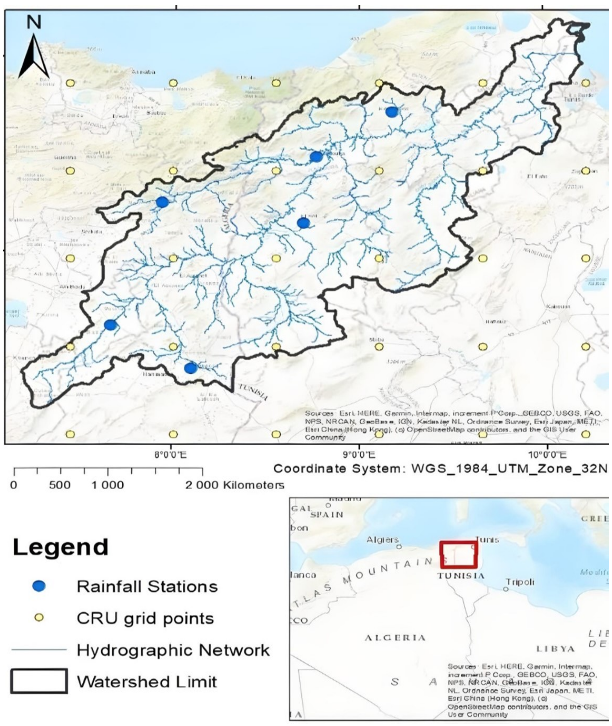

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**Figure 1**: The Geographical Location of the Medjerda Watershed.

Our study was undertaken in this context in order to evaluate the performance of the six Cordex-Africa regional RCM models that simulate rainfall at the Medjerda Watershed during the reference period (1981-2005). Our aim is to evaluate those RCMs selected that have been frequently used in climate impact studies on Africa. Those insights will serve as a reference for future research concerning the evaluation of climate change impacts in this study area.

## 2 Methodology

### 2.1 Study area

The Medjerda Watershed is located in the Northeast of Algeria and in the Northwest of Tunisia (Fig. 1). The Medjerda River is the longest river in the Tunisian-Algerian transboundary basin, with a total length of 485 km. Its source lies near Souk Ahras (Northeast Algeria) before flowing into northern part Tunisia and finally into the Mediterranean Sea (Gulf of Tunis). It collects most of northern Tunisia's water (80%). The entire basin has a total area of 23,700 km$^2$ of which 16,100 km$^2$ (68%) is located in Tunisia.

The selection of this basin as a study area in our research is based mainly on its geographical and hydrographic importance. It is considered to be one of the most important watersheds in the regions of the Maghreb and North Africa, and is important with respect to concerns regarding the

**Table 1**: The Rainfall Characteristics of the Rainfall Stations used in the Research.

| Name | Origin | X(°) | Y(°) | Z(m) | P mean (mm) | Study period |
|---|---|---|---|---|---|---|
| Souk Ahras | CRU | 7.94 | 36.26 | 653.74 | 768 | 1901-2021 |
| Meskiana (Oum El Baouaghi) | CRU | 7.67 | 35.63 | 836.09 | 503 | 1901-2021 |
| Tebessa | CRU | 8.10 | 35.41 | 842.53 | 365 | 1901-2021 |
| Le-Kef | CRU | 8.70 | 36.16 | 588.02 | 729 | 1901-2021 |
| Jendouba | CRU | 8.77 | 36.50 | 137.25 | 918 | 1901-2021 |
| Beja | CRU | 9.18 | 36.73 | 219.80 | 763 | 1901-2021 |

**Table 2**: The Name, Origin, and Acronyms of Climate Models (GCM and RCM)

| GCM | RCM | Institution | Acronym |
|---|---|---|---|
| CNRM-CERFACS-CNRM-CM5 | RCA4 | Swedish Meteorological and Hydrological Institute, Sweden | SMHI |
| CCCma-CnaESM2 | CRCM5 | University of Quebec in Montreal, Canada | UQAM |
| ICHEC-EC-EARTH | RACMO22T | Koninklijk Nederlands Meterologisch Instituut, Netherlands | KNMI |
| ICHEC-EC-EARTH | HIRHAM5 | Danish Meteorological Institute, Denmark | DMI |
| MIROC-MIROC5 | REMO2009 | Climat Service Center Germany, Germany | GERICS |
| MPI-M-MPI-ESM-LR | CCLM4-8-17 | Climate Limited-area Modeling Community, USA | CLMcom |

vulnerability of this area to climate change. It is therefore necessary to assess the socio-economic impact of this change in order to implement adaptation and mitigation measures so as to ensure the sustainability of water resources for both countries (Algeria and Tunisia). This basin has been selected as a study area in several research works (Kadir et al., 2020; Boulmaiz et al., 2022).

This basin is characterized by a continental climate with a Mediterranean influence, with hot summers and cold winters. The annual rainfall average of the study area during the 1901-2021 period varies between 365 mm to 918 mm (from minimum to maximum respectively – see Table 1), during this period decreased precipitation was noted in the study of Khedimallah et al. (2020), who analysed the rainfall variability of this watershed, recording a significant 36% reduction in rainfall. This high variability demonstrates the vulnerability of this basin to the impacts of climate change.

The observed rainfall data is from the Climatic Research Unit (CRU TS 4.06) of the University of East Anglia. This data is presented at a resolution of 0.5°x0.5° (50 km x 50 km) and is available at http://www.cru.uea.ac.uk/cru/data (last access: 30 June 2022). These figures are from six rainfall stations (Table 1) (three that belong to Algeria and three to Tunisia) located near the Algerian-Tunisian border, the CRU grid cells are closest to the rainfall station locations that have been used as the reference to compare data against the Cordex-Africa models (Fig. 1). This database has been used in several hydrological studies (Harris et al., 2020; Babaousmail et al., 2021).

In order to estimate historical precipitations at the six selected study regions (Table 1), the outputs of regional climate models presented in (Table 2), of the Africa-Cordex program, (available on the website https://cordex.org/, last access: 4 July 2022), were extracted to compare the output of the Cordex-Africa models with observed data. The CRU dataset was re-gridded into a resolution of 0.44° by 0.44° using a bilinear interpolation method, which is a widely-used resampling technique, as mentioned by Nikulin et al. (2012).

These six models were considered satisfactory for the Maghreb region and North Africa (including the Medjerda Basin) and when compared to the other available models, as confirmed by Zeroual et al. (2019) and Bichet et al. (2020). These models offer simulations of climatic variables on a monthly frequency during the 1901-2021 period, with a resolution of 0.44° (nearly 50 km).

## 2.2 Criterion for the Evaluation of Regional Climate Models (RCM)

### 2.2.1 The Percentage Bias (PBIAS)

The climate models possess a bias, which may be explained by a systematic error between the data simulated by the RCMs and those observed. The assessment of the ability of regional climate models to reproduce observations at the scale of the study area has been undertaken by estimating the percent bias (PBIAS), this measures the average tendency of the simulated values to be either larger or smaller than the values observed during the reference period (1981-2005):

$$PBIAS = 100 * \frac{\overline{P_{sim}} - \overline{P_{obs}}}{\overline{P_{obs}}} \tag{1}$$

With $\overline{P_{sim}}$ is the mean of simulated seasonal and annual rainfalls by RCMs; $\overline{P_{obs}}$ is the mean of observed seasonal and annual rainfalls at each evaluated location over the 1981-2005 period (25 years).

### 2.2.2 The Pearson Correlation Coefficient (r)

This coefficient shows the concordance between two variables. It is obtained by calculating the linear regression between the simulated rainfalls and the observed rainfalls. Its

**Table 3**: The Performance Results of Cordex-Africa Regional Climate Models (RCMs) at Annual and Seasonal Scales during the Reference Period (1981-2005), Algeria. Rows 1–6 correspond to Souk Ahras, rows 7–12 correspond to Meskiana, while rows 13–18 correspond to Tebessa.

| | Winter | | | Spring | | | Summer | | | Autumn | | | Annual | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **R** | **RMSE (mm)** | **PBIAS (%)** | **R** | **RMSE (mm)** | **PBIAS (%)** | **R** | **RMSE (mm)** | **PBIAS (%)** | **R** | **RMSE (mm)** | **PBIAS (%)** | **R** | **RMSE (mm)** | **PBIAS (%)** |
| RCA4 | -0.67 | 70.44 | 0.67 | 0.97 | 26.66 | 0.41 | 0.38 | 14.37 | -0.86 | -0.99 | 28.60 | 0.41 | 0.12 | 333.99 | 0.43 |
| CRCM5 | -0.49 | 62.84 | 0.60 | 0.94 | 34.02 | 0.52 | 0.78 | 7.99 | 0.48 | 0.95 | 44.02 | 0.64 | 0.84 | 446.59 | 0.58 |
| RACMO22T | -0.98 | 58.10 | 0.56 | 1.00 | 11.62 | 0.18 | -0.41 | 14.37 | -0.86 | -0.66 | 35.31 | 0.51 | 0.22 | 271.99 | 0.35 |
| HIRHAM5 | 0.95 | 73.62 | 0.71 | 0.37 | 24.27 | 0.37 | 0.81 | 6.94 | -0.42 | -0.94 | 32.30 | 0.47 | 0.31 | 369.76 | 0.48 |
| REMO2009 | -0.32 | 70.03 | 0.67 | 0.95 | 14.56 | 0.22 | 0.93 | 7.11 | -0.43 | -0.92 | 29.29 | 0.42 | 0.33 | 320.31 | 0.42 |
| CCLM4-8-17 | -0.86 | 73.48 | -0.70 | 0.19 | 40.00 | 0.61 | 0.79 | 2.29 | 0.14 | 0.57 | 41.25 | 0.60 | 0.69 | 471.06 | 0.61 |
| RCA4 | -0.62 | 75.14 | -1.26 | -0.76 | 102.38 | -2.19 | 0.98 | 127.67 | -8.02 | -0.50 | 73.24 | -1.61 | -0.29 | 1135.30 | -2.26 |
| CRCM5 | -0.93 | 50.50 | -8.5 | -0.65 | 88.39 | -1.89 | 0.27 | 124.56 | -7.82 | -0.92 | 58.79 | -1.29 | -0.66 | 966.72 | -1.92 |
| RACMO22T | 0.83 | 31.01 | -5.2 | -0.90 | 62.91 | -1.35 | 0.98 | 112.74 | -7.08 | -0.71 | 52.95 | -1.16 | -0.83 | 778.85 | -1.55 |
| HIRHAM5 | -0.39 | 29.76 | -5 | -0.98 | 88.63 | -1.90 | 0.24 | 111.57 | -7.01 | -0.01 | 58.17 | -1.28 | -0.53 | 864.39 | -1.72 |
| REMO2009 | 1.00 | 20.09 | -3.4 | -0.96 | 57.59 | -1.23 | -0.49 | 107.94 | -6.78 | -0.58 | 52.71 | -1.16 | -0.83 | 714.98 | -1.42 |
| CCLM4-8-17 | 0.87 | 46.30 | -1.29 | -0.91 | 81.33 | -2.26 | 0.33 | 103.60 | -6.73 | -0.79 | 53.28 | -1.55 | -0.46 | 853.53 | -2.34 |
| RCA4 | -0.31 | 98.66 | -2.74 | -0.54 | 114.99 | -3.20 | 0.72 | 134.81 | -8.76 | -0.25 | 88.11 | -2.56 | -0.34 | 1309.72 | -3.59 |
| CRCM5 | -0.77 | 72.49 | -2.01 | -0.51 | 97.95 | -2.72 | 0.27 | 123.48 | -8.03 | -0.76 | 71.04 | -2.07 | -0.56 | 1094.90 | -3.00 |
| RACMO22T | 0.95 | 54.49 | -1.51 | -0.73 | 75.01 | -2.09 | 0.97 | 117.26 | -7.62 | -0.64 | 67.38 | -1.96 | -0.73 | 942.39 | -2.58 |
| HIRHAM5 | 0.24 | 54.49 | -1.51 | -0.93 | 100.24 | -2.79 | 0.23 | 118.78 | -7.72 | -0.06 | 71.52 | -2.08 | -0.39 | 1035.08 | -2.83 |
| REMO2009 | 1.00 | 43.60 | -1.21 | -0.81 | 67.96 | -1.89 | 0.08 | 116.08 | -7.54 | -0.41 | 61.78 | -1.80 | -0.69 | 868.25 | -2.38 |
| CCLM4-8-17 | 0.87 | 46.30 | -1.29 | -0.91 | 81.33 | -2.26 | 0.33 | 103.60 | -6.73 | -0.79 | 53.28 | -1.55 | -0.46 | 853.53 | -2.34 |

formulation is as follows:

$$r = \frac{\sum_{i=1}^{n}(P_{obs} - \overline{P_{obs}}) * (P_{sim} - \overline{P_{sim}})}{\sqrt{\sum_{i=1}^{n}(P_{obs} - \overline{P_{obs}})^2} * \sqrt{\sum_{i=1}^{n}(P_{sim} - \overline{P_{sim}})^2}} \tag{2}$$

$P_{obs}$ and $P_{sim}$ are the observed and simulated rainfalls, respectively; $\overline{P_{obs}}$ and $\overline{P_{sim}}$ are the averages of the observed and simulated rainfall respectively for $i = 1...n$; where $n$ is the total number of seasonal and annual rainfall data over the 25-year analysis period (1981-2005). The value $r$ varies from 1 to 1. If $r$ is positive and close to 1. The relationship between the observed rainfall and the simulated rainfall by the models is linear, it is increasing and the scatterplot is concentrated around the regression line, and if $r$ is negative and close to -1 this indicates a perfect negative correlation between the values of observed and predicted rainfalls.

### 2.2.3 The Root Mean Squared Error (RMSE)

The RMSE is calculated from the observation values and then averaged for all simulations made with the different models. It measures the difference between simulations and the observed rainfall. The formulation is given as follows:

$$\sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_{sim} - P_{obs})^2} \tag{3}$$

$P_{sim}$ and $P_{obs}$ are the simulated and the observed rainfall respectively for $i = 1...n$; $n$ is the total number of seasonal and annual rainfalls data over the 25-year analysis period (1981-2005).

### 2.2.4 The Taylor Diagram

The Taylor Diagram was designed by Taylor (2001), this diagram shows the degree of correspondence between a set of data simulated by a climate model and a set of reference data (observations). This diagram is particularly useful for evaluating the relative performance of different climate models by summarising three criteria of performance, including correlation coefficient ($R$), standard deviation ($STD$), and centred root mean square error ($RMSEc$). If the simulation models fit well with the observations (the reference data), they will be closer to the point marked ”Ref”.

### 2.2.5 Taylor's Skill Score

This score helps in the classification of models such that the score is equal to 1 for a perfect match between the observed and simulated data, and equal to 0 for an inverse performance of the model. It results from the following relation:

$$TSS = \frac{4(1+R)^2}{(\sigma_{sim}/\sigma_{obs} + \sigma_{obs}/\sigma_{sim})^2 * (1+R_0)^2} \tag{4}$$

Where $R$ is the correlation coefficient between the simulations and the observed rainfall; $R_0$ is the maximum achievable correlation coefficient (in this study $R_0 = 1$), $\sigma_{sim}$ and $\sigma_{obs}$ are the standard deviations of the simulated and observed rainfall, respectively, and are calculated by taking the square root of the difference between the monthly rainfall $P_i$ (in the case of this investigation) and the mean monthly rainfall of the data set. The formula is as follows:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(P_i - \overline{P})^2}{n-1}} \tag{5}$$

$P_i$ is the monthly rainfall in the month $i$; $\overline{P}$ the mean of monthly rainfall of time-series data and $n$ is the number of time-series data.

TSS is now largely used in multiple studies that focus on evaluating the performance of climate models and their classification, as confirmed by Warnatzsch and Reay (2019); Glisan et al. (2019); Ngoma et al. (2021).

**Table 4**: The Performance Results of Cordex-Africa Regional Climate Models (RCMs) at Annual and Seasonal Scales during the Reference Period (1981-2005), Tunisia. Rows 1–7 correspond to Le Kef, rows 7–12 correspond to Jendouba, while rows 13–18 correspond to Beja.

| | Winter | | | Spring | | | Summer | | | Autumn | | | Annual | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **R** | **RMSE (mm)** | **PBIAS (%)** | **R** | **RMSE (mm)** | **PBIAS (%)** | **R** | **RMSE (mm)** | **PBIAS (%)** | **R** | **RMSE (mm)** | **PBIAS (%)** | **R** | **RMSE (mm)** | **PBIAS (%)** |
| RCA4 | 0.93 | 27.83 | 0.29 | 0.60 | 34.19 | 0.55 | -0.16 | 4.98 | 0.32 | 0.99 | 21.76 | 0.32 | 0.93 | 266.29 | 0.37 |
| CRCM5 | 0.96 | 51.16 | 0.53 | 0.53 | 37.54 | 0.60 | 0.63 | 1.49 | 0.09 | 1.00 | 35.55 | 0.52 | 0.88 | 377.23 | 0.52 |
| RACMO22T | 0.58 | 25.66 | 0.27 | 1.00 | 17.53 | 0.28 | -0.46 | 2.35 | -0.15 | 0.95 | 7.01 | 0.10 | 0.91 | 143.54 | 0.20 |
| HIRHAM5 | 0.58 | 48.78 | 0.50 | 0.78 | 37.09 | 0.59 | -0.59 | 8.19 | 0.52 | 1.00 | 35.21 | 0.52 | 0.93 | 667.02 | 0.91 |
| REMO2009 | 0.76 | 8.46 | -0.09 | 0.84 | 8.44 | 0.13 | 0.28 | 2.32 | -0.15 | 0.85 | 1.13 | 0.02 | 0.93 | 3.59 | 0.00 |
| CCLM4-8-17 | 1.00 | 21.23 | 0.22 | 0.85 | 32.26 | 0.51 | 0.97 | 5.70 | 0.36 | 0.93 | 9.70 | 0.14 | 0.93 | 206.68 | 0.28 |
| RCA4 | -0.67 | 49.74 | -0.59 | -0.67 | 95.86 | -1.68 | 0.83 | 141.25 | -10.99 | -0.94 | 65.31 | -1.12 | -0.61 | 776.88 | -0.85 |
| CRCM5 | -0.92 | 23.93 | 0.18 | 0.03 | 51.54 | -0.70 | -0.05 | 120.67 | -9.42 | -0.69 | 29.40 | -0.34 | -0.84 | 533.03 | -0.58 |
| RACMO22T | 0.86 | 6.02 | -0.07 | -0.73 | 54.46 | -0.96 | 0.56 | 122.76 | -9.55 | -1.00 | 45.44 | -0.78 | -0.93 | 406.43 | -0.44 |
| HIRHAM5 | 0.13 | 7.72 | -0.09 | -0.96 | 79.93 | -1.40 | 0.49 | 125.25 | -9.75 | -0.82 | 48.76 | -0.83 | -0.78 | 505.35 | -0.55 |
| REMO2009 | 0.85 | 4.41 | 0.05 | -0.89 | 48.83 | -0.86 | -0.80 | 110.32 | -8.58 | -0.97 | 36.24 | -0.62 | -0.88 | 293.32 | -0.32 |
| CCLM4-8-17 | 0.87 | 1.89 | 0.02 | -0.98 | 58.37 | -1.02 | 0.59 | 105.24 | -8.19 | -0.98 | 27.67 | -0.47 | -0.76 | 288.55 | -0.31 |
| RCA4 | -0.30 | 66.81 | 0.62 | 0.77 | 25.38 | 0.41 | 0.87 | 1.71 | 0.16 | 0.96 | 33.50 | 0.45 | 0.84 | 382.21 | 0.50 |
| CRCM5 | -0.78 | 1.70 | 0.02 | 0.78 | 11.80 | 0.19 | 0.82 | 5.79 | 0.52 | 1.00 | 19.19 | 0.26 | 0.90 | 115.44 | 0.15 |
| RACMO22T | -1.00 | 33.08 | 0.31 | 0.69 | 13.22 | -0.22 | 0.99 | 5.68 | -0.51 | 0.94 | 4.99 | 0.07 | 0.84 | 57.48 | 0.08 |
| HIRHAM5 | 0.22 | 59.14 | 0.55 | 0.85 | 13.56 | 0.22 | 0.87 | 2.47 | 0.22 | 0.94 | 43.97 | 0.59 | 0.83 | 357.43 | 0.47 |
| REMO2009 | -0.40 | 130.70 | -1.21 | 0.89 | 19.55 | -0.32 | 0.93 | 5.34 | -0.48 | 1.00 | 84.18 | -1.13 | 0.92 | 719.29 | -0.94 |
| CCLM4-8-17 | -0.02 | 16.04 | 0.15 | 0.23 | 4.09 | 0.07 | 0.49 | 4.13 | -0.37 | 0.86 | 19.71 | 0.27 | 0.91 | 107.14 | 0.14 |

# 3 Results and Discussion

## 3.1 A Statistical Evaluation of the Performance of the Regional Climate Models (RCMs) for Cordex-Africa

The performance evaluation of the six regional Cordex-Africa models was conducted on the annual and seasonal time scales at the Medjerda Watershed during the reference period (1981-2005). Three statistical performance criteria were used: correlation coefficient ($r$), the root mean square error ($RMSE$ (mm)) and the percentage of bias ($PBIAS$ %).

The results show that the models that perform more efficiently are those that satisfy stronger correlations between observed and simulated rainfall data, and a low value in terms of $RMSE$, with a less-biased percentage in terms of $PBIAS$.

On the Algerian side of the Medjerda Watershed (Table 3), it emerges that at an annual scale, in terms of correlation coefficient, the CRCM5 model marked the highest value when compared to the other models with $r = 0.84$ in the Souk Ahras station when compared to the other rainfall stations. In terms of $RMSE$, the RACMO22T model recorded a lower value of 271.99 mm when compared to the other models, and it was the least biased, with a percentage of 0.35% in terms of $PBIAS$.

On a seasonal scale, in terms of correlation coefficient, a good correlation was recorded with a value of $r = 1$ for tthe REMO2009 model in winter at the Meskiana and Tebessa stations, and for the RACMO22T model in spring at the Souk Ahras station. In terms of $RMSE$, the CCLM4-8-17 model scored a lower value of 2.29 mm in summer in the Souk Ahras. In terms of $PBIAS$, the RACMO22T model presents a less-biased result when compared to the other models used, with a percentage of $PBIAS = 0.18\%$ in the spring in Souk Ahras.

On the Tunisian side of Medjerda Watershed (Table 4), on the annual time scale, in terms of correlation coefficient, the RCA, CCLM4-8-17, REMO2009, HIRHAM5 models displayed a strong correlation of $r = 0.93$ at the Le Kef station. In terms of RMSE, the lowest value when compared to the other results obtained is $RMSE = 3.59$ mm for the REMO2009 model. In terms of $PBIAS$, the REMO2009 model recorded an accurate result with a PBIAS percentage of 0.

On the seasonal scale, high correlation of $r = 1$ was obtained at the Le Kef station by the models CCLM4-8-17, RACMO22T, CRCM5 and HIRHAM5 in winter, spring and autumn respectively. This result was recorded at the Beja station by the CRCM5 and REMO2009 models. In terms of $RMSE$, the REMO2009 model displayed a low value of 1.13 mm at Le Kef in autumn when compared to the results obtained by the other models. In terms of $PBIAS$, the lowest bias value was marked in winter, to the order of 0.02%, according to the two models CCLM4-8-17 and CRCM5 at the Jendouba and the Beja stations respectively, the same result was obtained in autumn by the REMO2009 model at the Le Kef station.

In terms of $PBIAS$, the results obtained displayed a common bias in the RCMs used (the Cordex-Africa models), the highest value was approximately 0.67%, and was registered by the RCA4 and REMO2009 models in winter at Souk Aharass, while the lowest bias value was reached in winter to the order of 0.02%, with the CRCM5 and CCLM4-8-17 models at Beja and Jendouba respectively, and the REMO2009 model in autumn at Le Kef.

In order to assess the reliability of the Cordex-Africa regional models, performance's lower thresholds may be proposed for these three performance criteria. These thresholds are: $r > 0.80$, $RMSE \leq 2$ mm and $PBIAS \leq 20\%$.

The results obtained agree with several studies that focus on evaluating the output performance of the regional models of the Cordex-Africa project, such as the study of Gyamfi et al. (2021). At the level of the Pra River basin (PRB, Ghana), this project evaluated the performance of nine

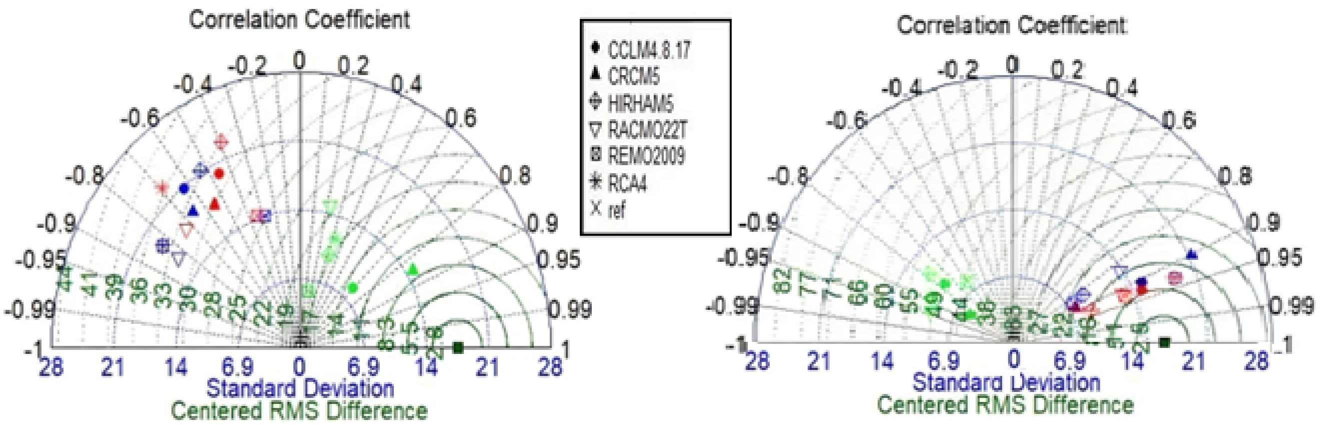

**Figure 2**: Results of the Taylor Diagram of the Cordex-Africa Regional Climate Model (RCM) at a Monthly Scale in (a) Algeria and (b) Tunisia during the Reference Period (1981-2005).

simulations of the RCA4 regional climate model of Cordex-Africa (CanESM2, HadGEM2-ES, MPI-LR, CNRM-CM5, CSIRO-Mk3, EC- Terre, IPSL, MIROC5, NorESM-1) by reproducing the observed rainfall over a 31-year period (1975-2005). At the annual scale, CanESM2 and IPSL produced an accurate prediction of the observed rainfall with average biases of 0.8% and 16.7% respectively.

On a monthly time scale, the simulation outputs of HadGEM2-ES indicated relatively accurate performance measures when compared to those observed. Kefeni et al. (2020) evaluated three models (MPI-ESM LR, CNRM-CM5, EC-EARTH), this assessment is based on the way in which the RCMs simulated the characteristics of the precipitation regime in the Upper Awash Sub-basin (Ethiopia) from 1985 to 2005, they found that the MPI-ES-LR climate model showed the best results in terms of correlation coefficient $r = 0.96$.

On an annual and seasonal time scale, the CRCM5, RACMO22T, CCLM4-8-17 models showed accurate results for the Algerian part of the Medjerda Watershed, and the REMO2009, CCLM4-8-17, CRCM5 models for the Tunisian side of the basin.

## 3.2 The Graphic Evaluation of the Performance of the Cordex-Africa Regional Climate Models (RCMs)

The Taylor diagram and Taylor's Skill Score (TSS) are used to evaluate the general performance of the Cordex-Africa models that reproduce monthly rainfall. The radial coordinate represents the magnitude of the standard deviation, while the mean squared difference is illustrated using the concentric half-cycle, the results show the models that represent good performance results on a monthly scale according to their response to the performance criteria (the Taylor Diagram and Taylor's Skill Score - TSS).

In the Algerian part of the Medjerda Basin (Fig. 2, a), the CRCM5 model is considered to be the most efficient, it is illustrated as the closest to the observations with a higher correlation of $r = 0.85$ and a low value RMSE of 8.3 mm, as it shows a higher value in terms of $TSS = 0.44$ (Fig. 3, a) when compared to the results obtained by other models.

In the Tunisian part of the Medjerda Basin (Fig. 2, b), all the models showed accurate results, except the Jendouba station, however, the CCLM4-8-17 model is shown to provide readings closer to the conditions observed, with a stronger correlation of approximately 0.95. This model showed the lowest RMSE value at approximately 11 mm and the highest TSS value, of 0.91, when compared to other models (Fig. 3, b).

We can therefore consider a performance lower threshold of $TSS > 0.5$ for TSS criterion when assessing the reliability of the Cordex-Africa regional model outputs.

Other studies have evaluated the performance of different Cordex-Africa models using the Taylor Diagram and TSS. Umuhoza et al. (2021) studied the performance of the RCA4 regional model for Cordex-Africa using ten GCMs during the 1951 to 2005 period in Rwanda (Central Africa), with the aim of selecting those models to be used for future climate projections. The models were classified according to satisfaction levels in terms of the evaluation criteria applied (Taylor Diagram, TSS) from the most efficient model to the least efficient: CSIRO, CanESM2,CNRM, GFDL, MIROC5, EC-Earth, HadGEM2, IPSL, MPI and NorESM1.

On a monthly time scale, the CRCM5 model is the best in terms of the Algerian region of Medjerda Watershed, while the CCLM4-8-17 model may be considered as the best model for the Tunisian region of the Medjerda Watershed, with the exception of Jendouba station.

To sum up, the results obtained in these two sections (3.1 and 3.2) revealed a common bias in the RCMs used (the Cordex-Africa models) due to limited spatial resolution (coarse spatial grid resolution of almost 50 km) that do not take into account more regional phenomena, such the orographic rainfall, so it is therefore necessary to consider these limitations before using models to assess the impacts of climate change on water resources.

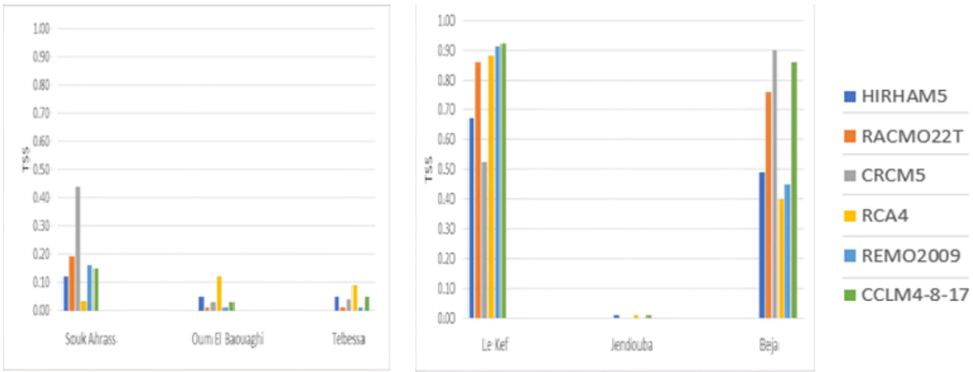

**Figure 3**: Results of the Taylor Competency Score (TSS) for the Cordex-Africa Regional Climate Model (RCM) on a Monthly Time Scale in (a) Algeria and (b) Tunisia during the Reference Period (1981-2005).

## 4 Conclusions

This study sought to evaluate the performance of six regional Cordex-Africa project models for the Medjerda Watershed in Northern Africa.

The ranking of the models based on their performance is: REMO2009, CCLM4- 8-17, RACMO22T, and CRCM5. However the RACMO22T and CRCM5 models may be considered as being more suitable for the eastern part of Algeria, while REMO2009 and CCLM4-8-17 are better-suited to the western part of Tunisia.

In light of our results, a performance threshold could be established for each criterion in order to assess the reliability of the Cordex-Africa regional model outputs. For rainfall variability it is preferable to reach the following thresholds values: $r > 0.80$, $RMSE \leq 2$ mm, $PBIAS \leq 20\%$ and $TSS \geq 0.50$.

Therefore, the results obtained in this study are fully consistent with previous studies that have been conducted in the context of the North African and Mediterranean regions.

This research highlights the importance of a performance evaluation of Cordex-Africa regional models, taking associated errors into account. We recommend correcting the bias of climate model outputs in order to obtain an accurate estimate of the hydrological response of the catchment area. The use of several climate models have allowed us to include an overall performance in order to subsequently explore a combination of adaptation strategies and management plans to combat the impacts of climate change.

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